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Application of Index Models for Assessing Freshwater Microplastics Pollution

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ABSTRACT

Due to the differences in reporting units and methodology on microplastics (MP) studies, there has been some difficulty in comparing results across studies. In this study, we presented index models that can be address this issue. Index models for pollution and health risks assessment was applied to MP data obtained from rivers in Nwangele L.G.A. Models such as microplastics contamination factor (MPCF), microplastics pollution load index (MPPLI), Microplastics polymer risk indices (H_i) and pollution risk index (MPR) for pollution and contamination assessment. Health risk models such estimated daily intake (EDI) and microplastic carcinogenic risks (MPCR) through oral and dermal pathway were also presented and applied. Results showed that there is no direct correlation of MP abundance with MPR. However, H_i correlated but with MPR. Increased MPs pollution risks and levels were extensively subject to the presence of harmful MPs polymers, just as the high MPs pollution loads index (MPPLI). The index models enabled easy comparison of MP pollution of the different rivers and provided concise information on the status of MPs in the rivers.

***Keywords*:** Carcinogenic, Estimated daily intake, Health risks, Modeling, Plastic pollution

1. INTRODUCTION

There is an increase in the global production of plastics and the amount of waste generated yearly. Plastics form microplastics (MPs) with general size of < 5 mm while in the environment

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from degradation processes (Enyoh et. al., 2020). Microplastics are increasingly being observed in all components of most aquatic ecosystems of the world and posing varying toxicological threats to virtually all aquatic biota (Cole et. al., 2015; Verla et. al., 2019). The adverse effects of their presence in the marine environment which include particle toxicity, chemical toxicity and microbial toxin to marine organisms and sea animals have been demonstrated and discussed in many studies (Hall et. al., 2015; Verla et. al., 2019). As studies on MPs increases, there have been some limitations as with reporting units and methodology and so it presents some problem in comparing data across studies. Therefore, to arrive at a decision or conclusion concerning the presence of MPs in a particular area or matrix can be very difficult.

The aforementioned limitation may be addressed using index models. The index is an algorithm that gives a single number as final result from measured variables computation, thereby expressing a measure of the qualitative state of the media. Information from models is viewed as simplified concepts of environmental issues and thus makes it easy for policy makers to understand environmental issues and this way decisions on are quickly arrived at. In this study, index models were applied to MPs data from inland fresh water system in Nigeria. The study provided handful information of the status of the rivers and be useful also for policy makers and environmentalist.

2. METHODOLOGY

The study area is Nwangele Local Government area of Imo state, South Eastern, Nigeria. Five rivers including OBIARAEDU (Abajah), NWANGELE (Abba), OKUMPI (Umuozu), OGBAJARAJARA (Isu) and ONUEZUZE (Amaigbo) located in the area were selected for the study. The complete description of the study area and sites can be found in Enyoh et. al., (2019). The sampling scheme and analytical method applied in this study can also be found in Enyoh et. al., (2019).

2. 1. Index modeling

2. 1. 1. Models for contamination and pollution assessment

2. 1. 1. 1. Microplastics contamination factors (MPCf) and pollution load index (MPPLI)

In calculating the microplastics contamination factors (MPCf) and pollution load index (MPPLI) in the surface water, the models originally developed by Fostner and Calmano (1993) and Thomilson et. al., (1980) were modified and presented in equation (1) and (2). The MPCf refers to the contamination of MPs in the studied surface water (MP_i) compared to the background values (MP_b). The ideal background value would be that from a sample for MP prior to the rapid development of the plastic industry. However, for this study, it was taken from the lowest MPs abundance recorded in the study [9.5 (mean)]. This was obtained in the upstream of the river (OKUMPI) which showed the lowest quantity of MPs (Enyoh et. al., 2019). However, microplastic pollution load index (MPPLI) was computed as the nth root of the product of individual MPCf.

$$MPCf_i = \frac{MP_i}{MP_b} \quad (1)$$

$$MPPLI_{Area} = (MPC_{f_1} x\, MPC_{f_2} x\, MPC_{f_3} \dots \dots . MPC_{f_n})^{1/n} \quad (2)$$

2. 1. 1. 2. Microplastics polymer risk indices and pollution risk index

The polymeric and pollution risks of MP were computed for the different surface water and also for the entire study area following the description presented by Kabir et. al., (2021). The equations for computing the polymer risks indices (H_i) and index (MPR_{area}) for the entire area are presented in equations (3) and (4). The equation (3) followed a modification of the ecological risks index developed by Hakanson et. al., (1980). The P_{ji} is the number of each single MPs polymer identified in sample i and the MPR_{area} is computed as the n^{th} root of the polymer risks indices products. The S_j is the chemical toxicity coefficient or risk scores, which is obtained from the hazard scores assigned by Lithner et al. (2011) for different polymers. The values were PE = 11; PET = 4; and PVC = 10001, PP = 1, and PS = 30.

$$H_i = \sum\left(\frac{P_{ji}}{MP_i} \times S_j\right) \quad (3)$$

$$MPR_{Area} = (H_A \times H_B \times H_C \times H_D \times \dots \dots . H_n)^{1/n} \quad (4)$$

The MPs pollution risks (MPRI), the equations (5) and (6) were computed adopted as described by Kabir et. al., (2021).

$$MPRI_i = H_i \times MPCf_i \quad (5)$$

$$MPRI_{Area} = (MPRI_A \times MPRI_B \times MPRI_C \times MPRI_D \times \dots \dots . MPRI_n)^{1/n} \quad (6)$$

2. 1. 2. Models for health risks assessment

2. 1. 2. 1. Estimated daily intake (EDI)

An individual risk pathway as a result of human exposure to microplastic contamination of water could be through oral ingestion or dermal during recreational activities. Therefore, the estimated daily intake (EDI) due to exposure to overall MPs resulting from ingestion and dermal routes of contaminated water was determined using equation (7) while the polymer based can be estimated using equation (8). The dermal routes of exposure were computed since skin pores, although vary by ethnicity and age, have been generally reported to range from 40 to 500 μm (Plewig and Kligman, 2000; Jo et. al., 2007; Kakudo et. al., 2011; Saedi et. al., 2013; Flament et. al., 2015). Therefore, MPs can potentially fit into these pores easily.

$$EDI_{Ingestion} = \frac{P_{ji} \text{ x RI}}{\text{Bw}} \quad (7)$$

$$EDI_{Dermal} = \frac{p_{ji} x\, SA\, x\, d_p\, x\, ABS\, x\, ET\, x\, FE\, x\, DE\, x\, CF}{Bw\, X\, AT} \quad (8)$$

where, $EDI_{q/p}$: estimated daily intake of MPs based on quantity (EDI_q) and polymer type (EDI_p) through ingestion of the water (particle/L/BWday); P_{ji} is the number of each single MPs polymer identified in sample i; RI: ingestion rate is (2.2 L/day for adults; 1.8 L/day for children); B_W: average body weight (70 kg for adults; 15 kg for children) as described in earlier reports (Ibe et al., 2020; Enyoh and Isiuku, 2020). FE: exposure frequency (365 days/year); DE: exposure duration (70 years for adults; and 6 years for children); AT: averaging time (365 days/year × 70 years for an adult; 365 days/year × 6 years for a child) SA (18000 cm^2) is the skin area available for contact, d_p (cm/hour) is the pore diffusion coefficient (see equation 9 and 10); ABS (unitless) is the dermal absorption factor (0.001) ; ET (0.58 h/event) is the exposure time, CF (0.001 L/cm^3) is the unit conversion factor.

$$d_p = \frac{D}{\tau} \tag{9}$$

The tortuosity factor (τ) relates the adsorbate diffusivity in the pore to the diffusivity in free solution. For this study, it is taken as a unit (1), since the pore diffusion coefficient is directly related to the molecular diffusivity of the adsorbate (D) (Valderrama et al., 2008) and computed according to Wilke and Chang, (1955), presented in equation 10.

$$d_p = D = \frac{7.4\times10^{-8}(\phi M)^{0.5}T}{\eta_b V_m^{0.6}} \tag{10}$$

where, ϕ: relates effective molecular weight of water with respect to the diffusion process, and has the value of 2.6, M: solvent molecular weight (water:18.01528 g/mol), T: temperature (for the rivers = 298.15 K), η_b: solution viscosity (1 cp), V_m : adsorbate (polymer) molecular volume (cm^3/mol), although vary by polymer and temperature can be estimated as the ratio of molar mass to the density. The V_m for the identified polymers was PS (98.90 cm^3/mol), PVC (45.30 cm^3/mol), PET (144 cm^3/mol), PP (49.3 cm^3/mol) and PE (32.3 cm^3/mol). Putting the different values in equation (11), d_p were 1.27×10^{-5}, 1.87×10^{-5}, 1.05×10^{-5}, 1.79×10^{-5}, and 2.21×10^{-5} for PS, PVC, PET, PP and PE respectively.

2. 1. 2. 2. MP carcinogenic risks assessment

The excess lifetime cancer risk for adults and children were calculated based on cancer slope factor (CSF) values. Cancer slope factor (CSF), is a parameter that arises during the quantitative risk assessment of chemicals or agents being evaluated as carcinogens. It represents a measure of cancer risk from a lifetime exposure to an agent. The CSF for vinyl chloride (PVC) is 1.9, for propylene (PP) is 0.24 (USEPA, 1992) while for ethylene (PE) and ethylene glycol/ terephthalic acid (PET) were not listed (USEPA, 1997). However, the CSF for ethylene oxide, which is 1.02, was adopted since it is used in production of polyethylene based plastics (e.g. PE and PET) (Salamone, 1996). Styrene (PS) was categorized as non-cancer and so CSF was not provided (USEPA, 1992). The cancer risk was evaluated by multiplying the average daily intake with a cancer slope factor (CSF). MPCR is estimated as the incremental probability of an individual developing cancer over a lifetime. The MPCR caused by a potential carcinogen exposure over a lifetime was evaluated using equation (11) while the total cancer risk (CRt) over a lifetime was calculated using equation (12).

$$MPCR_{oral/dermal} = EDI_{oral/dermal} \times CSF \tag{11}$$

$$MPCR_t = MPCR_{oral} + MPCR_{dermal} \tag{12}$$

3. RESULTS AND DISCUSSION

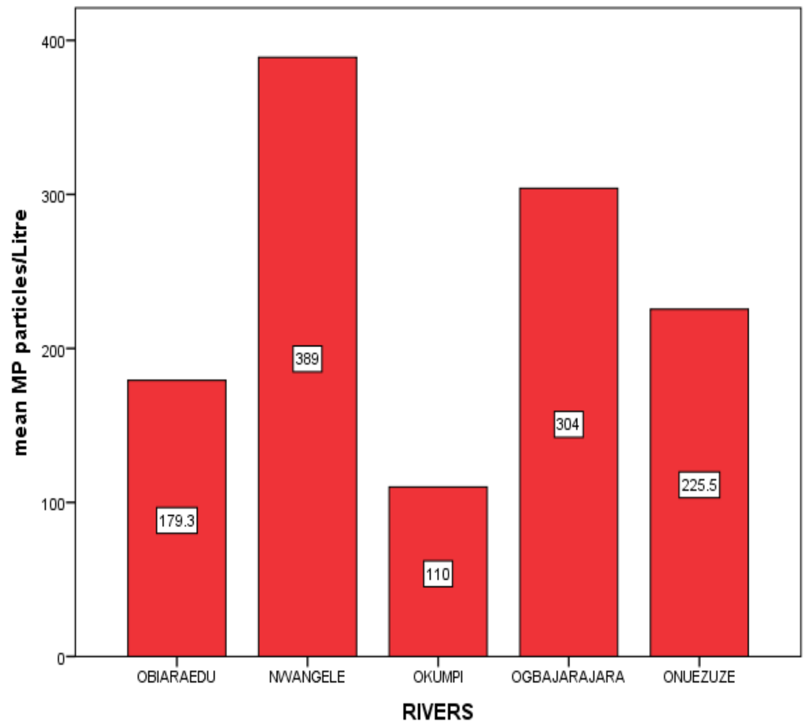

Figure 1. Quantity (mean) of microplatics in the rivers

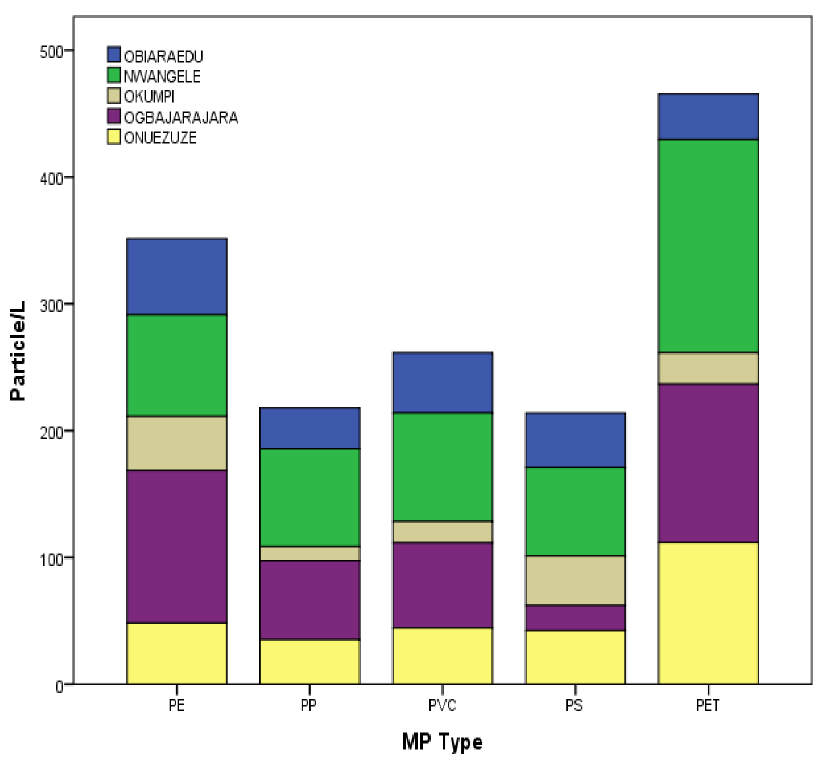

Figure 2. Distribution of MP types in the rivers

The amount (mean) of microplastics counted in in one liter of water sample collected upstream, midstream and downstream is presented in Figure 1. The highest and lowest quantity of MPs were recorded in NWANGELE an OKUMPI respectively. The distributions for MP types are presented in Figure 2. The samples generally contain PE, PP, PVC, PET and PS. Detailed discussion of distribution can be found the study of Enyoh et. al., (2019).

3. 1. Index model assessment

The application of index models for evaluating MP pollution load as well as risks is important as it help to quickly reach a decision. The index is an algorithm that gives a single number as final result from measured variables computation, thereby expressing a measure of the qualitative state of the surface water pollution by MP.

3. 1. 1. Microplastics contamination factors (MPCf) and pollution load index (MPPLI)

The microplastics contamination factors (MPCf) can be considered as a standardized monitoring and assessment approach for determining level of contamination between different samples. The accumulation or loading of MPs in the various rivers was estimated using MPCf, acknowledging that the MPs have different tendencies of accumulation in the rivers as they all experience different levels anthropogenic activities. High levels of accumulation may results to high risks and so expressing MP concentration as a determinant in the matrix in terms of a factor that is indicative of background limits can enable the matrix to be ranked according to their tendency to accumulate MPs.

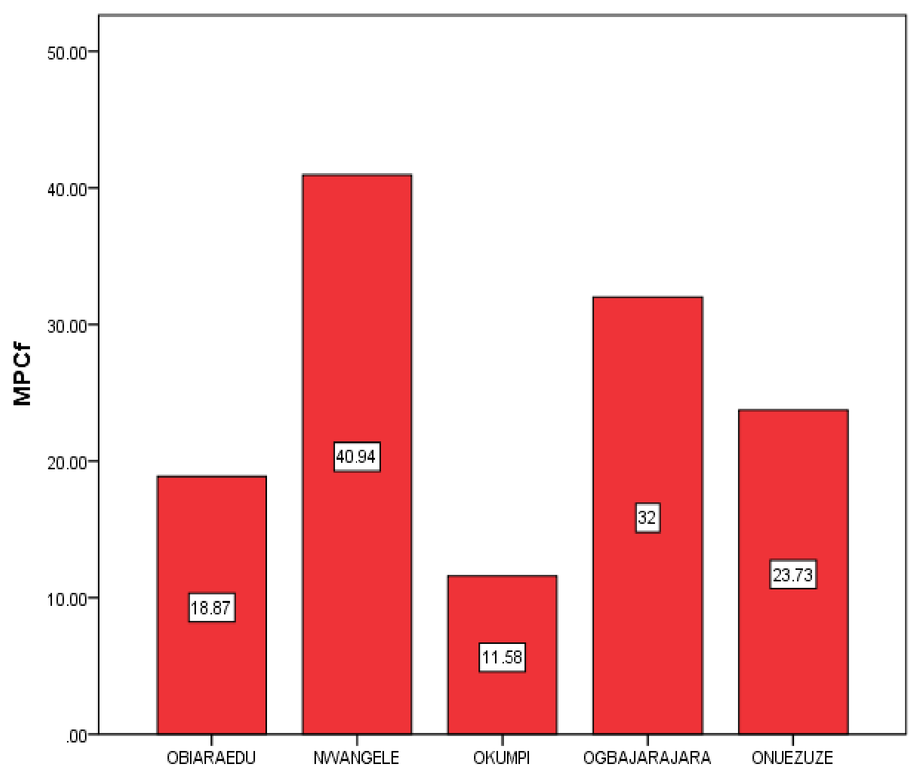

Figure 3. Microplatics contamination factors for the rivers

The MPCf were categorized as values with MPCf < 100 are low contamination, 100 ≤ MPCf <3 00 are moderately contaminated, 300≤ MPCf ≤ 600 are considerably contaminated and MPCf ≥ 600 very highly contaminated.

The results for the computed microplastics contamination factors and pollution load index are presented in Figure 3. Following the classification of MPCf, all samples (100 %) showed very high contamination. The overall pollution load is 23.25, indicating that the rivers in the area are polluted by microplastics. Contamination of drinking water by microplastics is undesirable due to the negative effects they pose to ecosystems (Enyoh et. al., 2020; Wang et. al., 2020).

3. 1. 2. Microplastics polymer risk indices and pollution risk index

The plastic polymer is viewed as biochemically idle because of its enormous sub-atomic size, and is in this way not viewed as perilous for environment and human wellbeing. Be that as it may, polymerisation responses are seldom finished and, accordingly, likewise unreacted residual monomers can be found in the polymeric material, a few of which are dangerous for human wellbeing and the environment or potentially influences polymer properties (Matlack, 2001). The remaining monomer substance may change a great deal contingent upon kind of polymer, polymerisation method and procedures for lessening residual monomer content (Araújo et al., 2002). Araújo et al. (2002) presented in their review that residual monomer substance for different polymers, in an audit by, differed from no or extremely low levels (100 ppm; for example 0.0001%) to up to 40,000 ppm (for example 4%). Other than the leftover monomers other polymerisation pollutions can be available in a plastic item. These incorporate oligomers, low atomic weight polymer sections, catalyst remnants, and polymerisation solvents, just as a wide scope of plastic added substances including handling helps and end products additives substances (Lithner et. al., 2011).

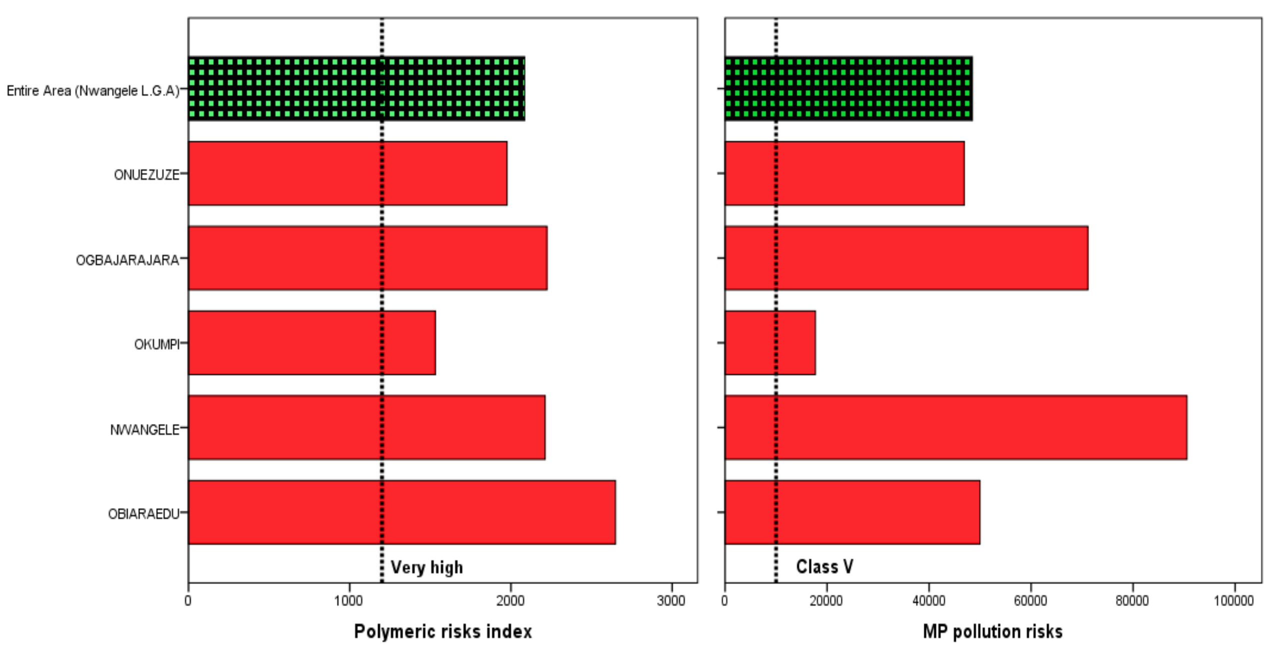

Figure 4. Microplastics polymer risk indices and pollution risk index for the rivers

These loads of non-polymeric segments are for the most part of low atomic weight and may, hence, relocate from the plastic item to environment and inturn into human where they may cause harm.

Therefore, it is pertinent to evaluate the polymeric risks indices of MPs as it quantifies the risks the MP may pose to health and ecosystems based on its composition. The results for the MP polymer risk indices (H_i) and pollution risk index (MPR) are presented in Figure 4. According to Kabir et. al., (2021), the classification for the Polymeric risk indices (H_i) is given as low when < 150, medium when 150-300, considerable when 300-600, high 600-1200 and very high when > 1200. Following the classification, all samples showed high risks with the following order Obiaraedu > Ogbajarajara > Nwangele > Onuezuze > Okumpi. The overall polymer risks for the area were 2085.12. This is largely due to the presence and high hazard scores of PVC (Lithner et. al., 2011). PVC contains dangerous chemical additives including phthalates, lead, cadmium, and/or organotins, which can be toxic to human health. These toxic additives can leach out or evaporate into the air over time, posing unnecessary dangers to human health and in particular children. Therefore, the presence of PVC plastics in the rivers should be prevented. However, there is no direct correlation of MP abundance and polymer risks but with pollution risks. This is in agreement with Kabir et. al., (2021), who also obtained high polymeric risks for some freshwater samples collected in Japan.

For MPs pollution risk index (MPRI), it is classified as follows: Class I when < 10, class II when 10-100, Class III when 101-1,000, Class IV when 1,001-10,000 and Class V when > 10,000 (Kabir et. al., 2021). All rivers also showed very high pollution risks (Class V), which followed the high polymer risks (Figure 4). Hence, increased MPs pollution risks and levels were extensively subject to the presence of harmful MPs polymers, just as the high MPs pollution loads index (MPPLI).

3. 1. 3. Microplastics estimated daily intake (EDI)

The interaction with freshwater could results to oral and dermal exposure to MPs during recreational activities. The results for computed estimated daily intake of MPs through oral ingestion and dermal routes for adult and children are presented in Table 1. All EDIs are generally less than 1 from dermal pathway, indicating low daily intake of MPs and therefore may pose no risks from daily contact. However, results via oral pathway showed values greater than 1 and suggests high daily intake and could pose risks to the consumer. The highest EDI was recorded for PET while other followed PE > PVC > PS > PP. Results further revealed a general higher intake of MPs for children than adult. Studies have generally suggested higher intake of MPs by children compared to adults (Nor et. al., 2021). Information on the risks of MPs to children's as well as adult health is still very unclear. Other than exposure, the fate and transport of ingested MPs in the human body, which incorporate intestinal assimilation and biliary discharge, have not been tended to in previous investigation and remained generally obscure. Amassing of MPs in the body tissues could cause actual pressure and harm, irritation, oxidative pressure, and insusceptible reactions (Wang et. al., 2020). Until this point, impact studies looking at MPs on human cells discovered little proof of effect on cell practicality. Nonetheless, it is questionable if the scope of exposure concentrations utilized in such investigations is really illustrative of the MP gathered in body tissues. Therefore, an urgent action is needed to evaluate the health implications of these MPs when they enter the human body. However, it is assumed as with other toxic chemicals, MPs may results to low intelligent quotient (IQ), stunted growth and organ underdevelopment in children.

Table 1. Estimated daily intake (particle/L/BWday) of microplastics.

MP type	Pathway	OBIARAEDU		NWANGELE		OKUMPI		OGBAJARAJARA		ONUEZUZE	
		Adult	children	Adult	children	Adult	children	Adult	children	Adult	children
PE	Oral	1.88	7.20	25.12	9.60	13.40	5.12	37.78	14.44	4.87	5.80
	Dermal	1.97E-7	9.23E-4	2.63E-7	1.23E-3	1.41E-7	6.56E-4	3.96E-7	1.85E-3	1.59E-7	7.43E-4
PP	Oral	10.15	3.88	24.18	9.24	3.45	1.32	19.57	7.48	11.09	4.24
	Dermal	8.62E-8	4.03E-4	2.05E-7	9.59E-4	2.93E-8	1.37E-4	1.66E-7	7.77E-4	9.42E-8	4.40E-4
PVC	Oral	14.86	5.67	26.90	10.28	5.23	2.00	21.14	8.08	13.91	7.72
	Dermal	1.32E-7	6.16E-4	2.39E-7	1.11E-3	4.64E-8	2.17E-4	1.88E-7	8.76E-4	1.24E-7	5.77E-4
PS	Oral	13.50	5.16	21.98	8.40	12.25	4.68	6.18	2.36	13.29	14.96
	Dermal	8.14E-8	3.80E-4	1.32E-7	6.19E-4	7.37E-8	3.45E-4	3.72E-8	1.74E-4	8.01E-8	3.74E-4
PET	Oral	6.38	4.32	32.75	20.16	7.75	2.96	39.15	5.08	9.89	13.44
	Dermal	5.63E-8	2.63E-4	2.63E-7	1.22E-3	3.86E-8	1.80E-4	1.95E-7	9.11E-4	1.75E-7	8.18E-4

3. 1. 4. MP carcinogenic risks assessment

In its simplest form, risk is the product of the hazard and exposure, but assumptions can greatly affect risk estimates. For example, cancer risk can be defined as the theoretical probability of contracting cancer when continually exposed for a lifetime (e.g. 70 years) to a given concentration of a substance (carcinogen). The probability is usually calculated as an upper confidence limit. The maximum estimated risk may be presented as the number of chances in a million of contracting cancer. The results of MP cancer risk (MPCR) of the heavy metals in the soil of the studied dumpsite are presented in Table 2.

Table 2. Microplastics carcinogenic risk index.

MP type	Pathway	OBIARAEDU		NWANGELE		OKUMPI		OGBAJARAJARA		ONUEZUZE	
		Adult	children	Adult	children	Adult	children	Adult	children	Adult	children
PE	Oral	1.92	7.34	25.62	9.79	13.67	5.22	38.54	14.73	4.97	5.92
	Dermal	2.01E-7	9.4E-4	2.68E-7	1.26E-3	1.44E-7	6.69E-4	4.04E-7	1.89E-3	1.62E-7	7.58E-4
PP	Oral	2.44	0.93	5.80	2.22	0.83	0.32	4.70	1.80	2.66	1.02
	Dermal	2.07E-8	9.67E-5	4.92E-8	2.30E-4	7.03E-9	3.29E-5	3.98E-8	1.86E-4	2.26E-8	1.06E-4
PVC	Oral	28.23	10.77	51.11	19.53	9.94	3.8	40.17	15.35	26.43	14.67
	Dermal	2.51E-7	1.17E-2	4.54E-7	2.11E-3	8.82E-8	4.12E-4	3.57E-7	1.66E-3	2.36E-7	1.09E-3

PET	Oral	6.51	4.41	33.41	20.56	7.91	3.02	39.93	5.18	10.09	13.71
	Dermal	5.74E-8	2.68E-4	2.68E-7	1.24E-3	3.94E-8	1.84E-4	1.99E-7	9.29E-4	1.79E-7	8.34E-4
MPCRt		39.10	23.46	115.94	52.10	32.35	12.36	123.34	37.06	44.15	35.32

According to U.S Environmental Protection Agency regulatory the acceptable cancer risk range is between 1×10^{-6} to 1×10^{-4} (USEPA, 2015). The MPCR via oral pathway was high for all polymer types (PE, PP, PVC, PS and PET) for both adult and children. PE was highest for in Ogbajarajara river while lowest in Obiaraedu. PP was highest in Nwangele and lowest in Okumpi river, PVC was highest in Nwangele and lowest in Okumpi river while PET was highest Ogbajarajara and lowest in Okumpi for both adult and children. This means that both the adult and children population were at risk of carcinogenic effects from oral of the different MP polymers. However, via dermal pathway the risks were very low as most values were comparable with the acceptable range .Based on the findings from this study, children are more at risk of cancer over a lifetime than adults. The ingestion exposure pathway is the major contributor to excess lifetime cancer risk from MPs in the rivers followed by dermal pathway.

4. CONCLUSION

In this study, index models for pollution and health risks assessment was applied to MP data obtained from rivers in Nwangele L.G.A. the microplastic (MP) contamination factors and pollution load index showed that the rivers were contaminated and loaded by MPs. The MP polymerics and pollution risks index were also high, indicating very high risks mainly due to the high polyvinyl chloride (PVC) present in the rivers. The estimated daily intake through oral pathway was high (> 1) and highest intake was shown by PET for both adult and children while via dermal pathway was low. Due to the presence of the different polymer, ingestion via oral pathway may cause cancer over a lifetime while via dermal may not. Finally, the index models enabled easy comparison of the MPs pollution of the different rivers and provided concise information on the status of MPs in the rivers.

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